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CHAPTER TWO: MATERIALS

AGGREGATES

Aggregates generally occupy approximately 75 percent of the concrete volume and strongly influence the concrete's hardened and freshly mixed properties. The properties of the aggregate have a major effect on the durability, strength, shrinkage, unit weight, and frictional properties of hardened concrete, as well as the mix proportions, slump, workability, pumpability, bleeding, finishing characteristics and air content of freshly mixed concrete. The selection of the proper aggregates and control of the use of those aggregates is essential in producing quality concrete mixtures.

Requirements

The QC/QA superstructure concrete specifications have several restrictions on the use of aggregates in concrete. They include:

1. The class of the fine and coarse aggregates shall be Class A or higher.

2. If the contract requires stay-in-place metal forms for the bridge deck or if the Contractor elects to use such forms, the bridge deck concrete shall incorporate class AP coarse aggregate.

3. Fine aggregate shall be natural sand.

4. Coarse aggregates shall be crushed limestone or dolomite, crushed or uncrushed gravel, or air cooled blast furnace slag.

5. The gradation of the fine and coarse aggregates shall be in accordance with size No. 23 and size No. 8, respectively, or a proposed alternate gradation for each.

6. If alternate gradations are proposed the tolerances for each sieve shall be as stated in the Quality Control Plan.

7. For coarse aggregates, 100 percent shall pass the 1 in. sieve.

8. The combined amount of fine and coarse aggregate passing the No. 200 sieve shall be from 0.0 to 2.0 percent for sand and gravel, and from 0.0 to 2.5 percent for sand and stone or slag.

9. The fine aggregate shall be no less than 35 percent or more than 50 percent of the total volume of the aggregate in each cubic yard, based upon saturated surface dry aggregates.

Fine aggregates and coarse aggregates are defined as follows:

Fine Aggregate -- Material that is 100 percent passing the 3/8 in. sieve and a minimum of 80 percent passing the No. 4 sieve

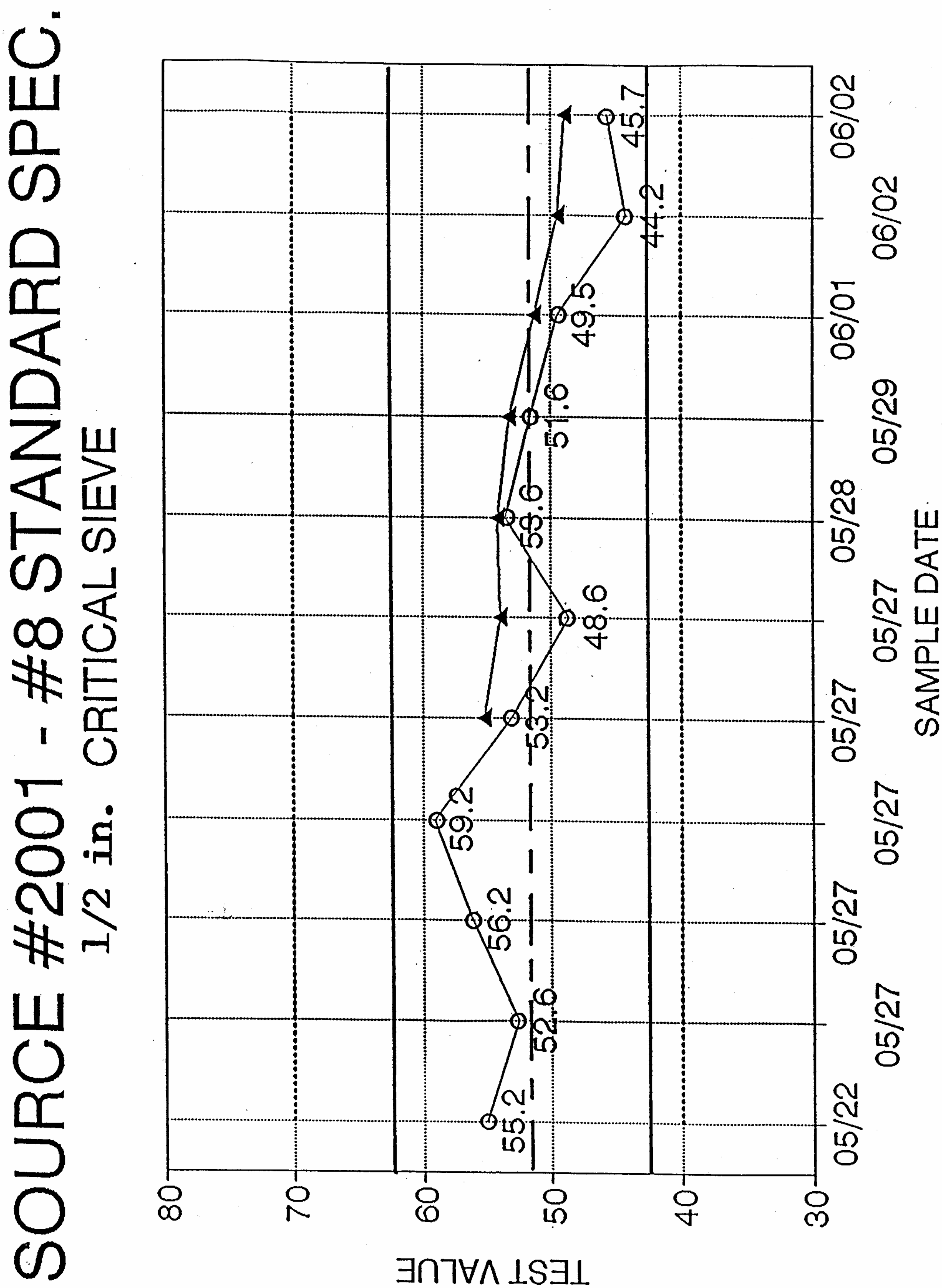
Coarse Aggregate -- Material that has a minimum of 20 percent retained on the No. 4 sieve.

Certified Aggregate Producer Program (CAPP)

The Certified Aggregate Producer Program is a program in which a qualified mineral aggregate Producer or Redistribution Terminal desiring to supply material to INDOT does so by assuming all of the Plant site controls and a portion of the testing responsibility that had been previously assumed by INDOT. The program focuses on production testing by the Producer and a site specific Quality Control Plan (QCP) that indicates how the Producer proposes to control the materials at the plant. Benefits of the program to the Producer include improved customer service, more plant control, and better documentation of test results and events at the plant. For INDOT the obvious benefit is that the Producer is providing material that has a consistent gradation.

The CAPP requires the source to conduct numerous tests on the aggregate as it is being produced and when it is shipped out. As a minimum, the gradation, decantation, crushed particle content, and deleterious tests are required, if applicable. Gradation, crushed particle content, and deleterious content are determined during production of the aggregate, and the gradation and decantation tests are conducted when material is loaded out.

Gradation tests are required to be plotted on a control chart by the Certified Aggregate Producer. A control chart is merely a graphic representation of the test data shown in conjunction with prescribed limits. Figure 2.1 illustrates an example of a control chart for the "critical sieve" (1/2 in.) of a No. 8 aggregate. The CAPP defines what the critical sieve is for each Standard Specification coarse aggregate material and this is the only sieve required to be plotted for coarse aggregates; however, all sieves having a gradation limit designated in the specification are required to be tested. Coarse aggregates not meeting the established limits of the Standard Specifications are classified as QA products and the Producer is required to designate the critical sieve and all the gradation limits in the QCP. Fine aggregate gradations are required to be plotted on control charts for all applicable sieves designated either in the Standard Specifications or in the QCP if the material is a QA sand.



SOURCE #2001 - #8 STANDARD SPEC.
1/2 in. CRITICAL SIEVE
TEST VALUE
80
70
60
50
40
30
55.2
52.6
56.2
59.2
53.2
48.6
53.6
51.6
49.5
44.2
45.7
05/22
05/27
05/27
05/27
05/27
05/27
05/28
05/29
06/01
06/02
06/02
SAMPLE DATE

FIGURE 2.1

Fine Aggregate Gradation

Fine aggregate shall be natural sand and meet the gradation requirements of No. 23 sand or a QA sand with a designated gradation from the Certified Aggregate Producer. No. 23 sand is the most common size of fine aggregate used. Figure 2.2 lists the gradation requirements for this material. The table requires that the sand be well graded and not have an excessive amount of particles on any sieve by limiting the amount retained on two consecutive sieves to no more than 45 percent.

Sieve Size	Min. % Passing	Max % Passing
3/8 in.	100	---
No. 4	95	100
No. 8	80	100
No. 16	50	85
No. 30	25	60
No. 50	5	30
No. 100	0	10
No. 200	0	3

Note: The fine aggregate shall have not more than 45% retained between any 2 consecutive sieves

FIGURE 2.2

Concrete mixtures lacking the proper amount of fine sand will be harsh and difficult to finish. In particular, the amounts passing the No. 50 and No. 100 sieves affect workability, surface texture and bleeding of concrete the most.

In general, if the water/cementitious ratio is kept constant and the ratio of fine-to-coarse ratio is chosen correctly, a wide range in fine aggregate gradations can be used without a measurable effect on compressive strength.

Fineness Modulus

The fineness modulus is an indicator of the fineness of an aggregate and is most used for evaluating fine aggregates. The higher the number, the coarser the aggregate. The fineness modulus is computed by adding the cumulative percentages retained on the 6 in., 3 in., 1 1/2 in., 3/4 in., 3/8 in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100 sieves, and then dividing by 100. The fineness modulus of a fine aggregate is useful in estimating the proportions of fine and coarse aggregates in concrete mixtures. An example of determining the fineness modulus of a fine aggregate is as follows:

Example:

Sieve Size	100	-	% Passing	=	% Retained
3/8 in.	100	-	100	=	0.0
No. 4	100	-	100	=	0.0
No. 8	100	-	89.2	=	10.8
No. 16	100	-	68.3	=	31.7
No. 30	100	-	45.1	=	54.9
No. 50	100	-	13.8	=	86.2
No. 100	100	-	2.6	=	97.4
					281.0

$$\frac{281.0}{100} = 2.81 = \text{Fineness Modulus}$$

Coarse Aggregate Gradation

Coarse aggregate shall be limestone, dolomite, gravel or air cooled blast furnace slag and meet the gradation requirements of a No. 8 coarse aggregate or a QA coarse aggregate with a designated gradation from the Certified Aggregate Producer. Also, the coarse aggregate is required to have 100 percent passing the 1 in. sieve. No. 8 coarse aggregate is the most common size used in superstructure concrete. Figure 2.3 lists the gradation requirements for this material. The specification requires that when the material is stone or slag the decant shall be 0 to 2.5 and when the material is gravel the decant shall be 0 to 2.0.

Sieve Size	Min. % Passing	Max % Passing
1 in.	100	---
3/4 in.	75	95
1/2 in.	40	70
3/8 in.	20	50
No. 4	0	15
No. 8	0	10
Decant *	0	1.5

* When the material is stone or slag, the decant may be 0 to 2.5

FIGURE 2.3

A coarse gradation is one having a percent passing each required sieve that is close to the bottom limit for that sieve (i.e., 75% passing the 3/4 in. sieve). Coarse aggregates with a coarse gradation, in general, require less water and cement than aggregate that are finer. The reason for this is that there is less surface area and therefore less cementitious requirement to adequately coat and bind the aggregate to other particles.

Mixture Gradation

The combined mixture gradation affects relative aggregate proportions as well as cement and water requirements, workability, pumpability, economy, porosity, shrinkage, and durability of concrete. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

Particle Shape and Surface Texture

Particle shape and surface texture of an aggregate predominately influence the properties of freshly mixed concrete. Rough-textured, angular, elongated particles require more water to produce workable concrete than do smooth, rounded, cubical-shaped particles. Concrete with an excess of angular particles may cause problems with workability and finishing. Irregular and angular particles that tend to interlock when consolidated will increase the strength of the mixture. Rough-textured particles give the cementing material something to grip, producing a stronger bond, and therefore also increase the strength of the mixture. Flat and elongated particles require an increase in mixing water and thus may affect the strength of concrete if the water/cementitious ratio is not maintained.

Specific Gravity

The specific gravity of an aggregate is the ratio of its weight to the weight of an equal volume of water. The value is used in computations for mixture proportioning and control, such as the absolute volume occupied by an aggregate. The specific gravity of an aggregate may be determined on an oven-dry basis or a saturated surface dry (SSD) basis. Oven-dry aggregates do not contain any absorbed or free water. Saturated surface dry aggregates are aggregates in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface.

The bulk specific gravity is determined by first drying the test sample to a constant weight in accordance with AASHTO T 84 and T 85. Both test methods allow the elimination of this initial drying if the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition. However, it should be noted that the absorption and bulk specific gravity (SSD) values may be significantly higher for aggregates that are not oven dried initially before soaking. This is especially true of particles with a high porosity since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

Mixture design and proportioning of QC/QA superstructure concrete are determined using bulk specific gravity (SSD) of each aggregate component. The bulk specific gravity determined on a dry basis is a common test conducted by the aggregate industry. However, using the absorption value of the aggregate, the bulk specific gravity (SSD) may be calculated in accordance with AASHTO T 84 and T 85 as follows:

$$S_s = (1 + A/100)\ S_d$$

where:

S_s = bulk specific gravity (SSD)
S_d = bulk specific gravity (dry)
A = absorption in percent

Example: $BSG_{(dry)}$ = 2.615
Absorption = 3.21%

$$S_s = (1 + 3.21/100)\ 2.615$$
$$= 1.0321 \times 2.615$$
$$= 2.699$$

The calculated bulk specific gravity (SSD) value is an estimate. QC/QA Superstructure Concrete specifications require that the actual bulk specific gravity (SSD) test value be used for mixture design and proportioning of concrete.

Absorption and Surface Moisture

The absorption and surface moisture (free moisture) of aggregates are required to be determined so that the net water content of the concrete can be controlled and the correct batch weights determined. Internally, aggregate particles are made up of solid mater and voids that may or may not contain water. Definitions of absorption and surface moisture, derived from AASHTO T 85 and AASHTO T 255, respectively, are as follows:

Absorption -- the increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles.

Surface Moisture (Free Moisture) -- the water adhering to the outside surface of the particles.

AASHTO T 255 designates the procedure for determining the total moisture content of the aggregate by drying that is required by QC/QA superstructure concrete specifications. The surface or free moisture content of a fine or coarse aggregate can be determined by deducting the absorption from the total moisture content.

The moisture conditions of aggregates at the jobsite and their contribution to the water in the concrete include:

1. Oven-dry -- no contribution to the water content.

2. Air Dry -- dry at the particle surface but containing some interior moisture. Particles have not reached full absorption and will absorb some water from the concrete mixture.

3. Saturated Surface Dry (SSD) -- particles have obtained the full absorption that is available and will neither absorb water from nor contribute water to the concrete mixture.

4. Damp or Wet -- particles have more moisture than the quantity needed for full absorption and will contribute water (free moisture) to the concrete mixture.

The amount of water used for the concrete mixture must be adjusted for the moisture content of the aggregates in order to meet the designated water requirement. The compressive strength, workability and other properties will be effected if the water content of the concrete mixture is not kept constant.

PORTLAND CEMENTS

Portland cements are finely ground powders that set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a solid mass. When the paste (cement and water) is added to aggregates, it acts as an adhesive and binds the aggregates together to form concrete.

Hydration of the cement begins as soon as there is contact with water. Each cement particle forms a growth on its surface that spreads until it connects with the growth of other particles or adheres to adjacent substances. This reaction results in progressive stiffening, hardening, and strength development. As the concrete stiffens there is a loss of workability that usually occurs within three hours of mixing; however, the composition and fineness of the cement, the mixture proportions, and temperature conditions all may have an affect on the loss of workability.

Hydration will continue as long as there is available space for the hydration products and the moisture and temperature conditions are favorable. The concrete will become stronger as the hydration continues. Most of the hydration and strength development will take place within the first month after mixing, and will continue slowly for a long time.

Requirements

QC/QA superstructure concrete allows the use of only Portland Cement (Types I, II or III), Portland Blast-Furnace Slag Cement (Type IS), or Portland-Pozzolan Cement (Type IP). Further restrictions on the use of portland cement include:

1. Cements shall be accepted by certification from qualified manufacturers or manufacturer/distributors. INDOT will maintain the approved list.

2. A means for storing and protecting the cement against dampness shall be provided. Cement which has become partially set, contains lumps or caked cement, or is salvaged from discarded or used sacks shall not be used.

3. Different kinds or brands, or cement of the same brand from different mills, shall not be mixed during use or used alternately in any one pour.

4. Type IS or type IP portland pozzolon cements may only be incorporated into concrete placed between April 1 and October 15 of the same calendar year. This time period restriction will not apply if traffic is not anticipated on the concrete or if silica fume is used as a portion of the total cementitious material.

5. If Type IP is used, the minimum portland cement content shall be increased to 600 lb/yd^3.

Portland Cement Types

Type I

Type I portland cement is a general-purpose cement suitable for all uses where special properties, such as sulfate resistance, high early strength, or low heat of hydration, are not required. It is used in concrete that is not subject to aggressive exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration.

Type II

Type II portland cement is used where it is important to protect the concrete form moderate sulfur attack. Also, Type II portland cement will usually generate less heat at a slower rate than Type I, which is important when concrete is placed in warm weather or in large structural elements where differential in thermal gradient is of concern.

Type III

Type III portland cement provides a high strength at a period of usually a week or less. It is used when forms need to be removed as soon as possible or when the structure is required to be put in service quickly. In cold weather, the curing period may be reduced.

Type IS

Type IS portland blast-furnace slag cement is used for general concrete construction applications. It is a blend of portland cement and granulated blast-furnace slag with the slag content between 25% and 70% by weight. These cements are produced by intergrinding the slag with the portland cement, separately grinding the slag and blending with the cement, or combining the grinding and blending of the two products.

Type IP

Type IP portland-pozzolon cement is used for general concrete construction applications. It is a blend of portland cement and a pozzolon with the pozollan content a maximum of 20% by weight. These cements are produced by intergrinding portland cement clinker with the pozzolon, by blending portland cement and a pozzolon, or by a combination of intergrinding and blending.

ADMIXTURES

Admixtures are those ingredients added to concrete immediately before or during mixing other than portland cement, water, and aggregates. The major reasons for using admixtures include:

1. To reduce the cost of concrete construction

2. To achieve certain properties in concrete more effectively than by other means

3. To insure the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather condition

The effectiveness of any admixture is dependent on such factors as:

1. Type, brand, and amount of cement

2. Water content

3. Aggregate shape, gradation, and proportions

4. Mixing time

5. Slump

6. Temperatures of the concrete and air

Trial batches of the project materials and the admixtures should be made to verify the compatibility of the materials as well as the effects on the properties of the concrete. The amount of admixture recommended by the manufacturer should be used.

Mineral Admixtures

Mineral admixtures are powdered or pulverized materials added to concrete before or during mixing to improve or change some of the plastic or hardened concrete properties. The mineral admixtures allowed in QC/QA superstructure concrete are classified as cementitious materials (ground granulated blast-furnace slag) and pozzolons (fly ash and silica fume).

Ground Granulated Blast Furnace Slag

Ground granulated blast-furnace slag is a nonmetallic material that is developed in a molten condition simultaneously with iron in a blast furnace. A glassy granular material is formed when molten blast-furnace slag is rapidly chilled by immersion in water. This glassy granular material is then ground to cement fineness resulting in ground granulated blast-furnace slag. The rough and angular-shaped ground slag hydrates and sets in a manner similar to portland cement when exposed to water and portland cement.

Fly Ash

Fly ash is a finely divided residue that results from the combustion of pulverized coal in electric power generating plants. In general, class F fly ash is produced from burning anthracite or bituminous coal and class C fly ash is produced from burning lignite or subbituminous coal. During combustion, the coal's mineral impurities (such as clay, feldspar, gravity, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gas. In the process, the fused material cools and solidifies into spherical particles called fly ash, which is collected by electrostatic precipitators or bag filters.

Silica Fume

Silica Fume is a powdery product that is the result from reducing high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrsilicon alloy. In the process, silica fume rises as an oxidized vapor from a 3630°F furnace, cools, condenses, and is collected in cloth bags. The condensed silica fume is then processed to remove impurities.

Mineral Admixture Effect on Concrete

The effects of the ground granulated blast-furnace slag, fly ash, and silica fume on the concrete are as follows:

<u>Fly Ash</u>

1. Enhances workability
2. Lowers permeability
3. Lowers water demand
4. Slightly enhances long term strength
5. Reduces the heat of hydration
6. Retards setting time
7. Delays strength gain

Ground Granulated Blast-Furnace Slag

1. Increases strength
2. Lowers permeability
3. Improves sulfate resistance
4. Lowers heat of hydration
5. Reduces potential alkali-silica reaction
6. Improves workability and pumpability

Silica Fume

1. Increases unit weight
2. Increases durability
3. Decreases permeability
4. Enchances strength
5. Increases mixing time
6. Reduces workability
7. Enhances pumpability

Requirements

QC/QA superstructure concrete has the following restrictions on the use of mineral admixtures:

1. Fly ash and ground granulated blast-furnace slag may only be incorporated into the concrete between April 1 and October 15 of the same calendar year. These dates will not apply if traffic is not anticipated on the concrete.

2. Fly ash will not be permitted in conjunction with the use of type IS or IP cements, or with ground granulated blast-furnace slag.

3. When silica fume is used the following criteria shall be used:

    a. The minimum portland cement content shall be 530 lb/yd^3 with a tolerance not to exceed one percent as directed by 702.06

b. The minimum and maximum cementitious content with silica fume shall be 650 - 715 lbs/yd^2

c. Silica fume shall constitute 7.0-7.5 percent of the total cementitious content in the mix design

d. Class F or C fly ash may be used as part of the total cementitious content. The maximum Portland cement/fly ash ratio shall be 6.4 by weight

e. The water/cementitious ratio shall be no less than 0.370 and shall not exceed the maximum of 0.420

f. The minimum compressive strength at 28-days shall be 5800 psi.

Chemical Admixtures

Chemical admixtures are materials added to concrete before or during mixing, that affect the concrete as follows:

Air-Entraining Admixtures -- used to entrain microscopic air bubbles in concrete.

Water-Reducing Admixtures -- used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water/cementitious ratio, or increase slump.

Retarding Admixtures -- used to retard the rate of setting of concrete.

Accelerating Admixtures -- used to accelerate strength development at an early age.

High-Range Water Reducers (Superplasticizers) -- added to concrete with low-to-normal slump and water-cement ratio to make high-slump flowing concrete.

Requirements

QC/QA superstructure concrete is required to contain an air entraining agent and either a water reducing, high range, admixture (Type F), or water-reducing, high range, and retarding admixture (Type G) as identified in the INDOT list of approved PCC Admixtures and Admixture Systems.. The following restrictions apply:

1. The type of admixture used shall not be changed during any individual contiguous pour.

2. When either the air or concrete temperature is expected to be 65°F or above and dead load deflection is of concern, a Type G admixture or HRWRR Admixture System shall be used.

3. If a fly ash or ground granulated blast-furnace slag admixture is used, the dosage of Type F or Type G may be lowered to an amount as recommended in writing by the manufacturer of the admixture.

4. A Type F admixture or HRWR Admixture System shall be used when both air and concrete temperatures are expected to be below 65°F or dead load deflection is not of concern.